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Simulation Consequences of Harmonic Recompense via PQ Based PI Controller for Grid Connected Current Controlled DG Part

Meysam Iranpour*

Electrical expert of Al Mahdi Aluminum Company. Hormozgan. Iran.

***Corresponding author Email: Iranpour.m8349@yahoo.com**

ABSTRACT

With the development of new technologies and electronic devices, one of the main topic of special concern is the aspect of power quality, amongst which control and prediction of harmonics are of utmost importance. The presence of harmonics caused by nonlinear loads which are common in Industrial plants and large scale office buildings means a threat to the sensitive equipments like that of computers, adjustable speed drives, power electronics load etc. Harmonic pollution causes electrical noises, sensitive equipment malfunctioning, tripping of circuit breakers, accelerated ageing of equipments, excessive temperature rises in motors which ensures the importance of harmonic mitigation in power system, also its mitigation is important in order to avoid the fines & costs associated with the poor power quality they are responsible for. The proposed technique discussed in this paper uses P,Q theory and PI controller to mitigate the Grid connected Solar DG unit harmonics with closed loop power control. It is a current controlled technique basically an Active Harmonic Filtering Technique. The proposed DG unit also achieves Zero Steady state tracking error. Simulated results in MATLAB validates the correctness of this method.

Keywords: Active power filter, Distributed Generation, Harmonic Compensation.

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1. INTRODUCTION

Today's world is called the electronic world, no doubt the technologies has gained more momentum in these few years ,but with the development of new emerging electronic devices comes the aspect of power quality. The term power quality, as defined in IEEE 1159 -1995, refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location on the power system [1].In the past power quality issues were only reserved for large industrial sector but today power quality is a problem for all because in the mid 20th all the utilities provided stable and smooth power and only few had power quality issues but today with the advent of more advance technology more efficient devices are being added to the grid due to which nonlinear loads are increasing and causing power quality issues. Nonlinear loads are the ones which does not have same waveform as that of the waveform of the current it draws. The voltage determines the quality of electric power and high quality voltage gives the guarantee for best operation of equipments. The most common types of power quality problems are sag/swell, over voltages, notches, Transients, flicker, Harmonic, noise, blackouts etc amongst which the prediction and control of harmonics are very important.

Harmonics are steady-state distortions to current and voltage waves, which repeats after every cycle. Harmonic waveform is nothing but the distortion of normal sinewave. Harmonic distortion means the waveform contains higher order frequencies i,e multiples of fundamental 60Hz frequency & it affects both voltage and current. Harmonic current distortion is mainly caused due to "Non linear loads" like VFDs, electronic devices, computers and all those devices that are energy efficient. Harmonic current distortions are very common in industrial and commercial places and the effects of this pollution including tripping of circuit breakers, capacitors overheating etc has to be reduced by some available mitigation techniques like that of Active & Passive Harmonic Filtering techniques. On the other hand Harmonic voltage distortions also has very harmful effects like that of motors overheating, failure of sensitive equipments etc.

Harmonics can be measured by a Distortion factor i,e Total Harmonic Distortion (THD) for both voltage and current.

$$\%THD_V = \frac{\sqrt{\sum_{h\neq 1} V^2{}_h}}{V1} . 100 \quad \& \qquad (1)$$

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$$\%THD_I = \frac{\sqrt{\sum_{h\neq 1} I^2{}_h}}{I1} .$$
100

Filters used for Harmonic Filtering can be Active, Passive or Hybrid. Active filters which are normally used for harmonic filtering minimize the current harmonic as well as improve the power quality. Active Filters has the following advantages over passive filter:

a. Active filters unlike passive do not resonate with the system.

b. they can improve the power factor as well along with harmonics.

c. More than one harmonic at a time can be addressed with Active filters.

d. Moreover these filters are more effective and they adjust itself to mitigate the current harmonics for each nonlinear load.

However, Active filters are always added in Parallel to nonlinear load and when both the currents i,e current harmonics and current of active filter combine together they cancel out each other.

2. EXISTING HARMONIC MITIGATION TECHNIQUES

There are many harmonic mitigation techniques including conventional feeder resonance voltage compensation, conventional local load harmonic compensation, active harmonic filtering using current controlled method etc. The Figure shown below is the conventional local load harmonic compensation method where the single phase DG systems is connected to the distribution system with a coupling choke (L_F, R_f) and the load is connected at the PoC. The lower part is the DG unit control scheme in which the current reference consists of two parts. The first one is the fundamental current reference I_{ref_f} and the second one is the harmonic current referenceI_{ref_h}. The fundamental PoC voltage $V_{PoC\alpha\_f}$ and its orthogonal component $V_{PoC\beta\_f}$ are obtained by using SOGI [2] as

$$V_{PoC\alpha\_f} = \frac{2\omega_{D1}s}{s^2 + 2\omega_{D1}s + \omega^2 f} . V_{PoC} \quad (2)$$

$$V_{PoC\beta\_f} = \frac{2\omega_{D1}\omega_f}{s^2 + 2\omega_{D1}s + \omega^2{}_f} . V_{PoC} \quad (3)$$

Where,ω_{D1} is the cutoff bandwidth of SOGI and ω_f is the fundamental angular frequency.

The relationship between power reference and the fundamental reference current for single-phase DG system can be established in α-β reference frame as follows:

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$P_{ref}=\frac{1}{2}(V_{PoC\alpha\_f}\cdot I_{ref\alpha\_f}+V_{PoC\beta\_f}\cdot I_{ref\beta\_f})$
$Q_{ref}=\frac{1}{2}(V_{PoC\beta\_f}\cdot I_{ref\alpha\_f}-V_{PoC\alpha\_f}\cdot I_{ref\beta\_f})$

Where,$I_{ref\alpha\_f}$ and $I_{ref\alpha\_f}$ are the DG fundamental current reference and its orthogonal component in the artificial α-β reference frame. Similarly, $V_{PoC\alpha\_f}$ and $V_{PoC\beta\_f}$ are the PoC fundamental voltage and its orthogonal component, respectively.

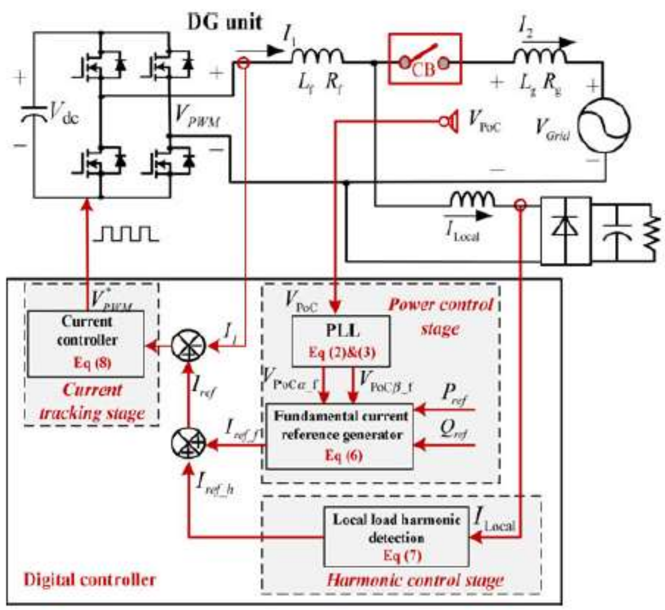

Fig.1: DG unit with local load harmonic current compensation capability [8].

According to (4), (5), and (20), the instantaneous fundamental current reference (I_{ref_f}) of a single-phase DG unit can be obtained as

$$I_{ref\_f}=I_{ref\alpha\_f}\frac{2(V_{PoC\alpha\_f}\cdot P_{ref}+V_{PoC\beta\_f}\cdot Q_{ref})}{V^2{}_{PoC\alpha\_f}+V^2{}_{PoC\beta\_f}} \quad (6)$$

Moreover, to absorb the harmonic current of local nonlinear load, the DG harmonic current reference (I_{ref_h}) is produced

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$$I_{ref\_h} = G_{D(s)} \cdot I_{\text{Local}} = \sum_{h=3,5,7,9,\dots} \frac{2\omega_{D2}s}{s^2 + 2\omega_{D2}s + \omega^2 h} \tag{7}$$

Where $G_{D(s)}$the transfer function of the harmonic extractor. To is, realize selective harmonic compensation performance [7], [9], $G_{D(s)}$is designed to have a set of band pass filters with Cutoff frequencyω_{D2}. With the derived fundamental and harmonic current references, the DG current reference is written as $I_{ref}= I_{ref\_f}+ I_{ref\_h}$. Afterward, the proportional and multiple resonant controllers [8], [13]. [14], [15] are adopted to ensure rapid current tracking.

$$V^*{}_{\text{PWM}} = G_{cur(s)} \cdot (I_{ref} - I_1) = \left(K_p + \sum_{h=f,3,5\dots\dots15} \frac{2K_{ih}\omega_c\, s}{s^2+2\omega_c\, s+\omega^2 h}\right) \cdot (I_{ref\_f}+ I_{ref\_h} - I_1) \tag{8}$$

Where V^*P is the reference voltage for pulse width modulation (PWM) processing, $K_p$the proportional gain of the current controller $G_{cur(s)}$,$K_{ih}$the resonant controller gain at the order$h$, $\omega_c$the cutoff frequency of the resonant controller, and $\omega_h$isthe angular frequency at fundamental and selected harmonicfrequencies.

An improved power control method with consideration of PoC voltage magnitude fluctuation [12] was developed. The main objective of local load harmonic compensation method is to ensure sinusoidal grid current I_2 in Fig 1. In PoC harmonic voltage mitigation capability,DG unit should not actively regulate the PoC voltage quality because, when it is connected to the main grid through a long underground cable with nontrivial parasitic capacitance, PoC voltage can be

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distorted [3] , [4].for such cases the feeders are always modeled by an LC ladder [4], [5], [6].In order to deal with the resonance issue associated with long underground cables, the R-APF concept can also be embedded in the DG unit current control as shown in Fig 2. As compared to Fig 1, the DG harmonic current reference in this case is modified as

$$I_{ref\_h} = \left(\frac{-1}{Rv}\right) . (GD(s) \cdot V_{PoC}) \tag{9}$$

Where Rv is the virtual damping resistance at harmonic frequencies? With this harmonic current reference in (9) , the DG unit works as a small equivalent harmonic resistor at the end of a feeder, when viewed at the power distribution system level [10], [11].The voltage quality at different positions of the feeder can be improved by

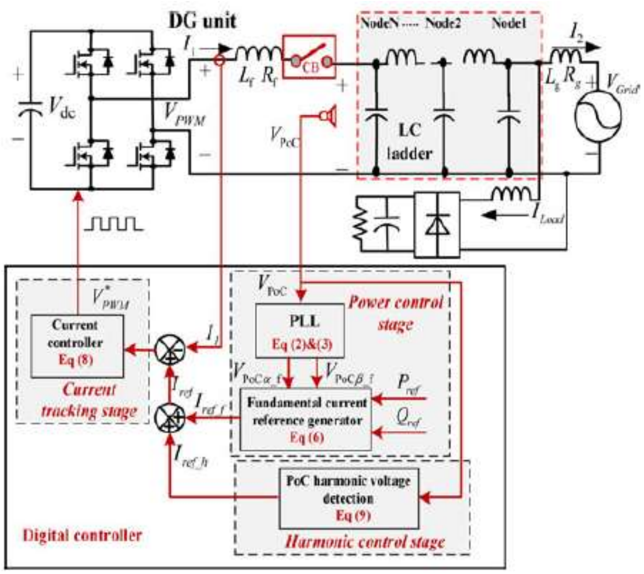

Fig.2: DG unit with PoC harmonic voltage mitigation capability [8].

Providing sufficient damping effects to the long feeder.

As discussed in the above two methods the harmonic currents was absorbed by the DG units. The interaction between DG harmonic current and PoC voltage may cause some steady state DG power

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offset [16]. The reference current using (6) was determined in an open loop manner which cannot address the power offset introduced by harmonic interactions.so in order to achieve accurate reference

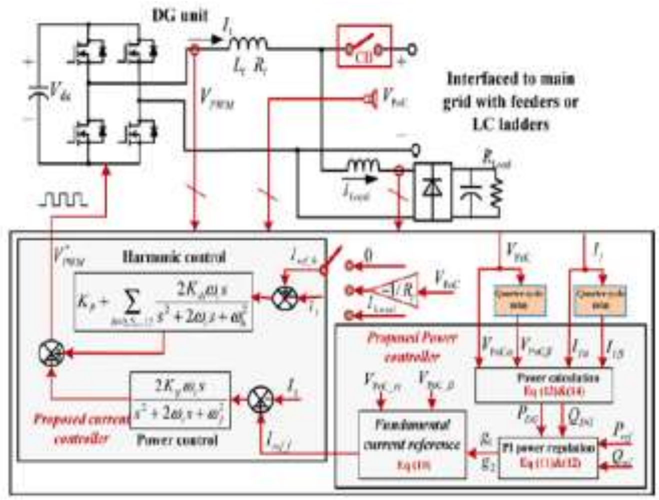

Fig.3: DG unit with current controlled active harmonic filtering (closed loop power control method) [8].

Current closed loop power control strategy can be used which is given as

$$I_{ref\_f} = g_1 \cdot V_{PoC\alpha} + g_2 \cdot V_{PoC\beta} \quad (10)$$

Where $V_{PoC\alpha}$is the nonfiltered PoC voltage expressed in the $\alpha - \beta$ reference frame ($V_{PoC\alpha}$=V_{PoC}) and $V_{PoC\beta}$is its orthogonal component. The gains $g1$ and $g2$ are adjustable and they are used to control DG unit real and reactive power, respectively. The detailed regulation law is shown as follows:

$$g_1 = \left(k_{p1} + \frac{k_{I1}}{s}\right) \cdot \left(\frac{1}{\tau s+1} \cdot P_{ref} - P_{DG}\right) + \frac{P_{ref}}{(E^*)^2} \quad (11)$$

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$$g_2 = \left(k_{p2} + \frac{k_{I2}}{s}\right) \cdot \left(\frac{1}{\tau s+1} \cdot Q_{ref} - Q_{DG}\right) + \frac{Q_{ref}}{(E^*)^2} \qquad (12)$$

Where k_{p1}, k_{I1}, k_{p2} , and k_{I2} are proportional and integral control parameters, P_{ref} and Q_{ref} are the real and reactive power references, $E*$ is the nominal voltage magnitude of the DG unit, τ is the time constant of first-order low-pass filters. P_{DG} and Q_{DG} are measured DG power with low-pass filtering as

$$P_{DG} = \frac{1}{2\left(\frac{1}{\tau s+1}\right)} \cdot (V_{PoC\alpha} \cdot I_{1\alpha} + V_{PoC\beta} \cdot I_{1\beta}) \qquad (13)$$

$$Q_{DG} = \frac{1}{2\left(\frac{1}{\tau s+1}\right)} \cdot (V_{PoC\alpha} \cdot I_{1\alpha} - V_{PoC\beta} \cdot I_{1\beta}) \qquad (14)$$

Where $I_{1\alpha}$ is the nonfiltered DG current expressed in the stationary $\alpha - \beta$ frame ($I_1 = I_{1\alpha}$) and $I_{1\beta}$ is its delayed orthogonal component. Note that in (13) and (14), the power offset caused by harmonic voltage and harmonic current interactions is also considered.

3. PROPOSED HARMONIC MITIGATION TECHNIQUE

The proposed harmonic compensation method develops the reference compensation current from the PQ based controller (single phase PQ theory). The Advantage of using single phase PQ theory uses very simple calculations for deriving the reference current under imbalances due to the power defects and also this theory is effective and flexible from designing point of view. This reference current obtained from this theory can be used to track the switching of converters and thus harmonics in the power supply can be reduced. The power components p and q are related to α, β voltage and current as follows

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$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

$$\therefore P_{act} = V_\alpha i_\alpha + V_\beta i_\beta$$

$$\& Q_{act} = - V_\beta i_\alpha + V_\alpha i_\beta$$

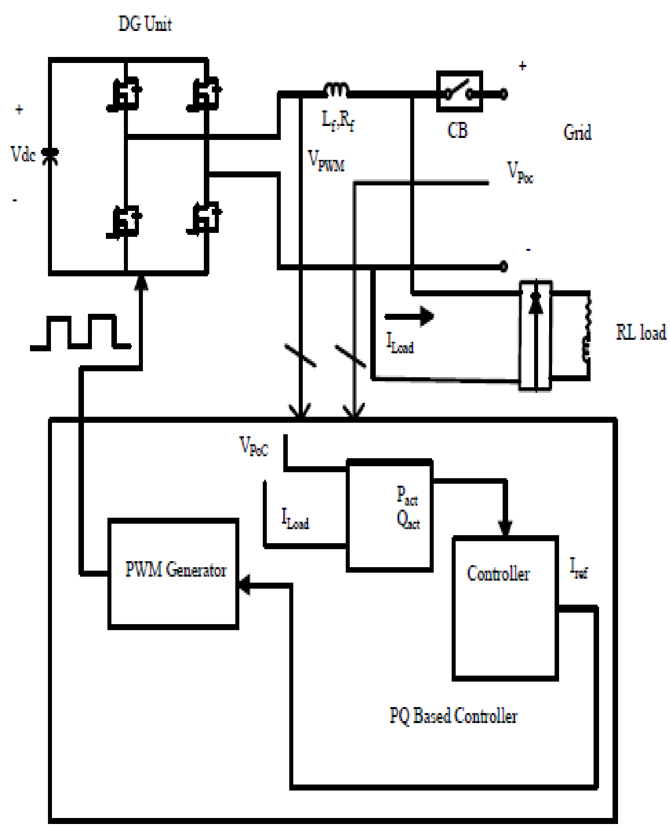

Fig.4: Proposed harmonic compensation method without high pass filter

In this method active harmonic filtering method is used because passive harmonic filtering method has certain disadvantages like

a. They only filter the frequencies they were previously tune for, b. resonance can occur because of interaction between passive filter and the other loads.

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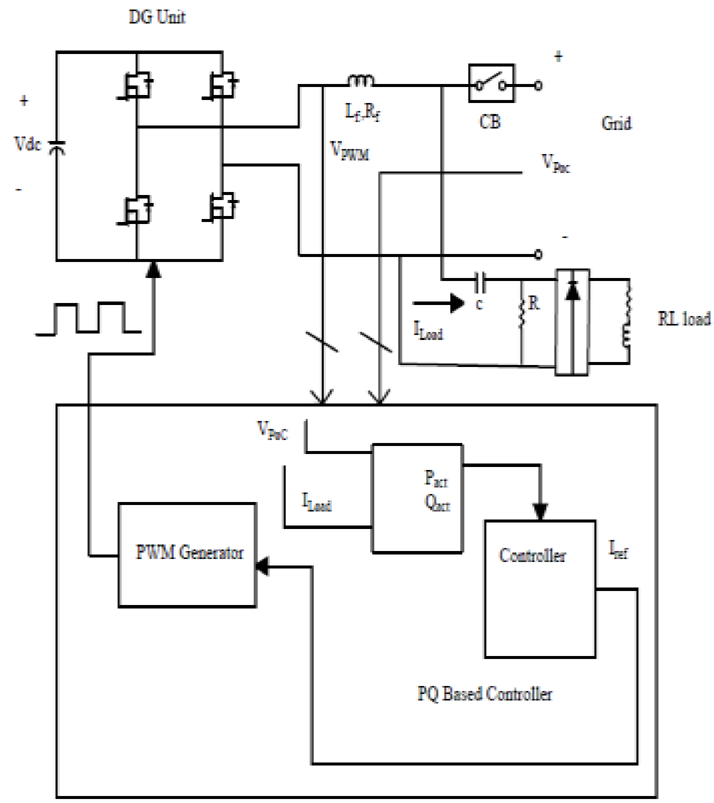

Fig.5: Proposed harmonic compensation method with high pass filter

Table.1: Parameters used in simulation.

System Parameters	Value
Grid voltage	Simulation 230V/50Hz
Grid Filter	L_f = 6.5mH ,R_f = 0.15 Ω
Sampling/Switching frequency	20Hz/10Hz
Power Control Parameter	Value
Real power Control K_{p1},K_{i1}	K_{p1} = 0.0001 , K_{i1} = 0.001
Reactive power Control K_{p2},K_{i2}	K_{p2} = 0.0001 , K_{i2} = 0.001

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4. SIMULATION RESULT

The simulation was carried out by using Matlab and the parameters used for simulation are tabulated in table 1.The simulation for harmonic compensation has been done without HPF and with HPF.

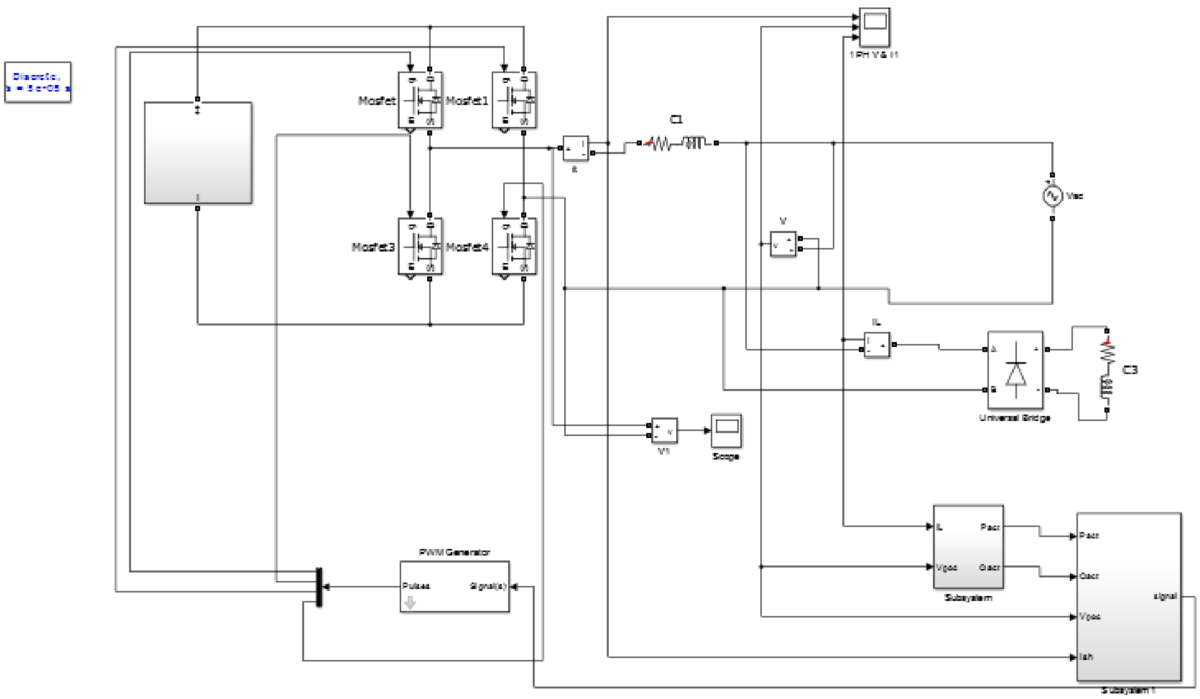

Fig.6: Matlab simulation without HPF (High pass filter)

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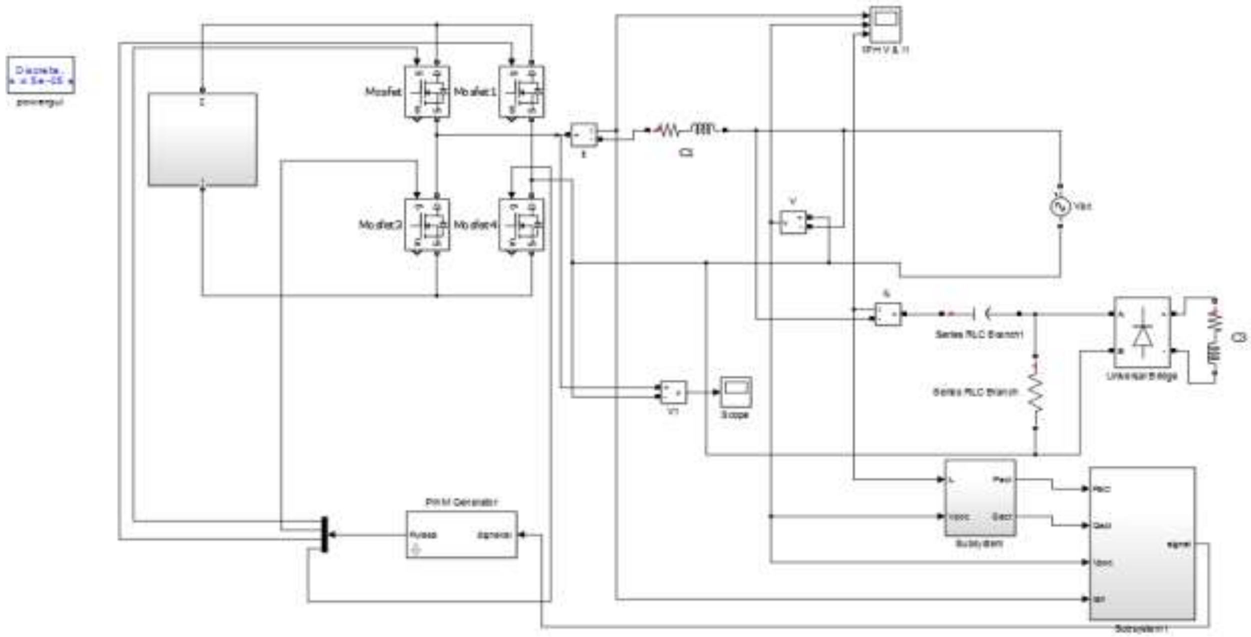

Fig.7: Matlab simulation with high pass filter

Voltage and current waveforms without HPF are

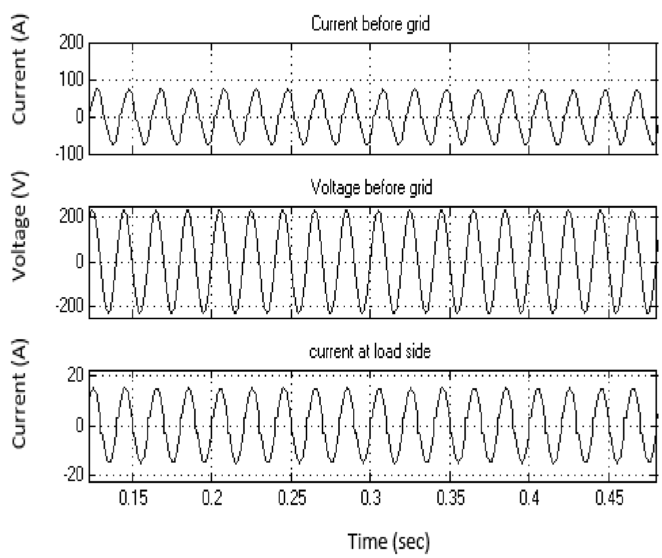

Fig.8: Voltage and current waveforms obtained from simulation (without HPF)

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Fig 9 shows the voltage and current waveform with HPF. The total harmonic distortion before compensation was 12 % (depending on load) with RL load (here,R =15 ohms & L = 10e-3)

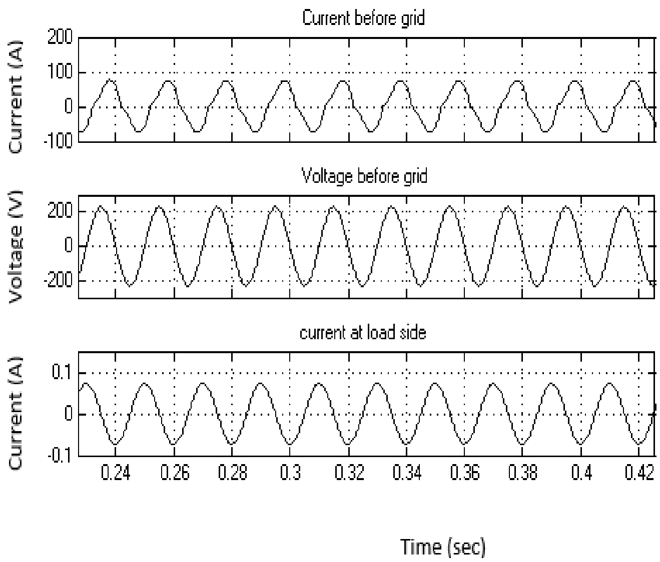

Fig.9: Voltage and current waveforms with HPF

FFT analysis shows that after compensation the THD was found to be almost 6.56% as shown in figure 10.

By using HPF the THD can be further reduced to 3% as shown in Fig 11.

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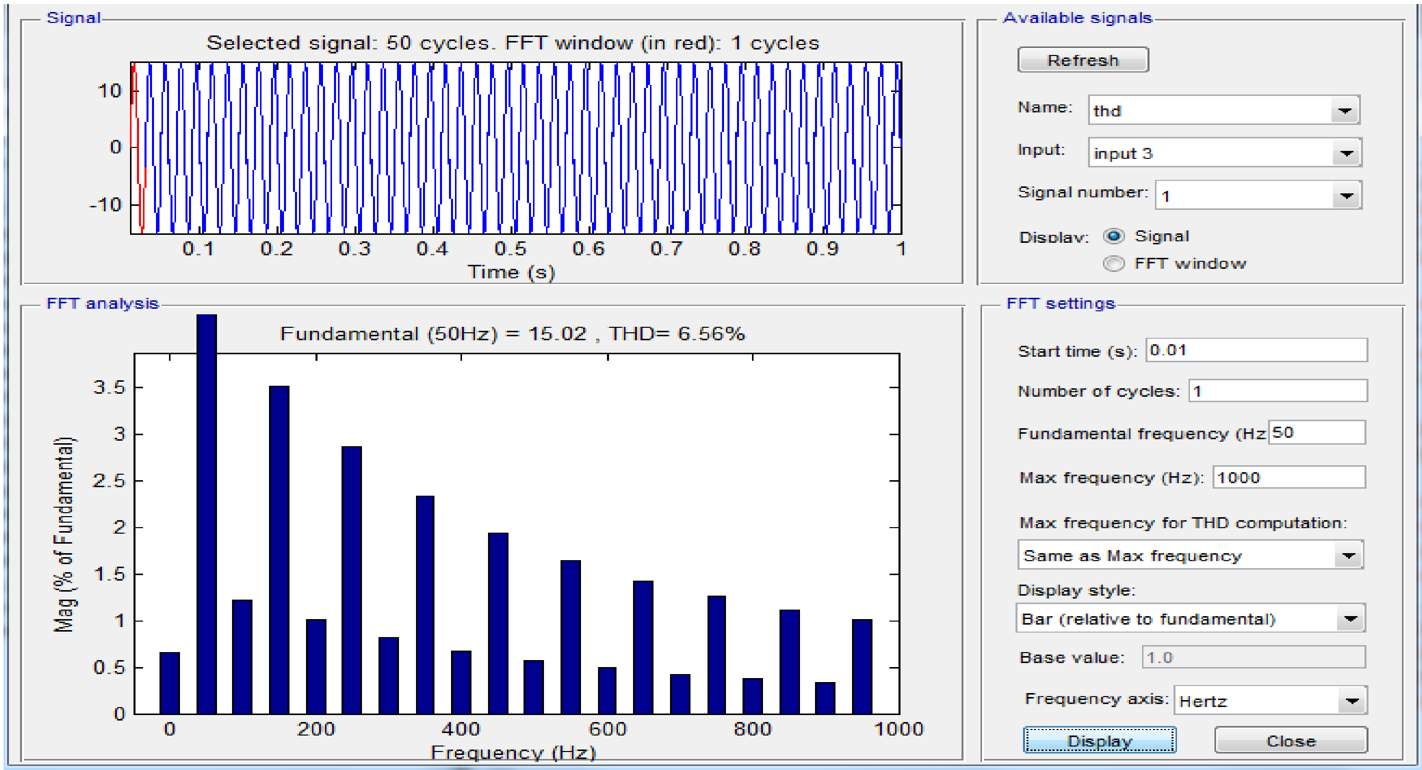

Fig10:FFT analysis THD without HPF

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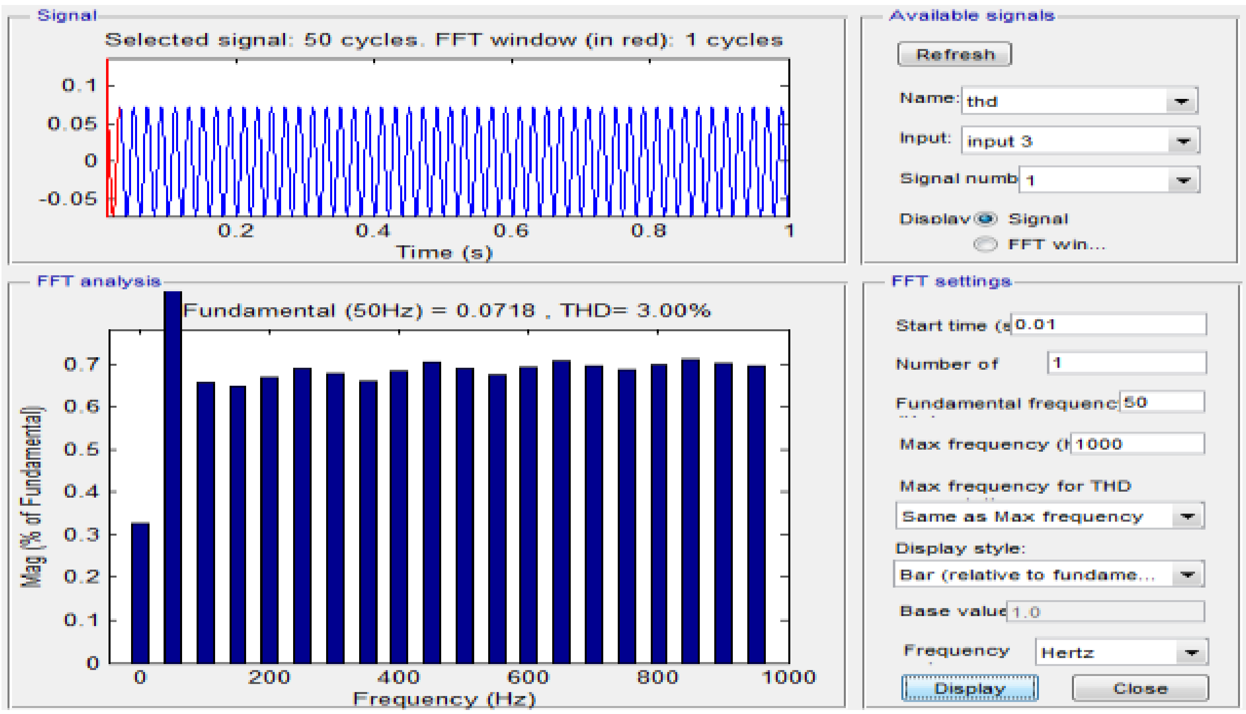

Fig.11: FFT analysis THD with HPF

5. CONCLUSION

As power quality has a very bad impact on the sensitive equipments, its mitigation is very important.Among all the power quality issues, prediction, control and compensation of harmonics is of foremost importance so this paper has discussed the compensation of Grid connected DG unit's harmonic compensation method by using PQ based PI controller technique. The DG unit harmonic compensation has been carried out for both with High pass filter and without high pass filter. This paper has also discussed the THD harmonic analysis. The simulations results were also carried out in Matlab which validates this harmonic compensation technique.

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